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TITLE: Studies of Rifle Effectiveness

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ABSTRACT: Scientific studies at Aberdeen Proving Ground have provided data which can be used in the design of improved small arms. An extended study of ten shooters using eight weapons on short-exposure-time targets yielded information concerning accuracy, rifle configuration, weight, type of sight, line of sight with reference to barrel and stock, recoil, trigger operation, time for functioning of firing mechanism and bore time of bullet, and barrel mass. A figure of merit having the dimensions of inch-seconds was developed as an index of rifle effectiveness. The factors of training, physique, physical condition, eyesight, reaction time, coordination and self discipline of the individual shooter were studied. Conclusions were reached as to characteristics desirable for rifles to be used against short-exposure-time targets. A study to investigate the factors of sighting error were conducted with three individuals using a sighting-error recorder, which records the error in sighting only. Ten-trial exercises were conducted and the data were reduced in the same manner as that for accuracy tests. Tests were conducted to determine the consistency of sighting error; the effectiveness of various types of sights at normal and low levels of illumination; and the effect on sighting error of type and size of front and rear sights, distance of sights from eye, target, and firing position. Conclusions were reached regarding the effect of sight characteristics on sighting error.

STUDIES OF RIFLE EFFECTIVENESS

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The rifle has been used as a tool to impact a projectile on a particular target for about 400 years. Since the rifle is the most common weapon of our armed forces, and the most important single weapon, improvement of its effectiveness is important to national defense. Development of the military rifle has been influenced greatly by useage and nontechnical considerations. It is for this reason that a scientific and engineering approach to the study of rifle effectiveness is greatly to be desired.

Many of the tests conducted at Aberdeen Proving Ground have yielded data that permit studies in rifle effectiveness. In addition to standard engineering tests on a wide range of domestic and foreign rifles, and development tests on experimental and standard models, several extensive tests were conducted to obtain basic information on rifle effectiveness.

An investigation, to obtain a comparison of rifle effectiveness when firing at short-exposure time targets, was completed in 1960. In this study ten individuals with various training, eight weapons, five types of sights, and standard and specially-loaded ammunition were used (1). A range with seven targets equally spaced on an arc of 60 degrees and at a range of 40 yards was used in conjunction with a control mechanism capable of exposing the targets in any order and for any time desired. A six-inch-diameter, round, aiming point was used. The time of target exposure and the distance of the shot hole from the center of a 30-inch diameter target were recorded.

When firing on short-exposure-time targets both time and accuracy must be considered by the rifleman since the two are interrelated. The situation will generally indicate to the shooter the accuracy required and the time available. Should the shooter be required to shoot quickly, the average shot will be less accurate than one fired deliberately and, when he is required to make a shot with great accuracy, a longer time is required. A figure of merit (distance of the shot from the target center multiplied by the time from full target exposure to the shot) was introduced on the basis of this theory to permit a more convenient evaluation of effectiveness. Since both time and accuracy are major considerations in effectiveness on short-exposure-time targets, the test was designed to obtain data under two conditions: when the shooter attempted to obtain the smallest figure of merit without a limit on firing time (best combination of accuracy and time), and when the target exposure time was established and the best accuracy in this time was desired.

This test was designed to introduce a number of major variables. Shooters were employed who had various backgrounds and skills in rifle shooting. Weapons were selected which represented both military and sporting models, and various types of mechanism. It was attempted to minimize the effect of learning, fatigue and weather by means of the firing schedule. It was not the purpose of this test to evaluate either weather or the individual shooter but these factors are of such great importance that they must be considered in evaluating weapon characteristics.

The effect of the following factors of weapon effectiveness were observed in this study:

a. Weather (visibility, wind and temperature)
b. Individual shooter
c. Weapon characteristics

1) Accuracy
2) Configuration
3) Weight of weapon
4) Type of sight
5) Line of sight with reference to stock and barrel
6) Recoil
7) Trigger operation
8) Time for functioning of firing mechanism and bore time of bullet
9) Barrel mass

Another investigation was completed in 1961. In this study the sighting error only was determined without a limitation of time. A facility was used which permitted the sighting error to be recorded directly without consideration of errors caused by rifle and ammunition. In using this sighting-error recorder the sights remain fixed during the test and the aiming point is moved by means of Synchro-Torque Transmitters and Snychro-Torque Receivers. When the desired sight alignment is obtained the individual operates a switch which causes a spark to pass through a paper on which an index point has been established. Each exercise consisted of ten trials. The groups were measured in the same manner as for fired accuracy targets. Trials were conducted to determine the consistency of sighting error; the effectiveness of various types of sights under normal and low levels of illumination; and the effect on sighting error of type and size of front and rear sights, distance of sights from eye, target, and firing position.

Mechanical, physiological and psychological factors must be considered in a study of rifle effectiveness for a particular condition of light and weather because the accuracy obtained is dependent on both the individual and the rifle-ammunition combination.

The firing cycle of the rifle is initiated when the rifleman applies a sufficient force to the trigger to disengage the hammer from the trigger. The hammer rotates and contacts the firing pin which is forced forward to contact the primer. The primer cup is deformed and the priming mixture is crushed between the cup and anvil. This causes initiation of the priming mixture which in turn ignites the propellant. The pressure of the gas generated by the burning propellant forces the bullet from the case and through the bore. When the bullet leaves the case the rifle moves to the rear according to Newton's third law.

It is advantageous to use a free-body diagram in a study of rifle effectiveness. On the diagram attached the recoil force (F_r) is on the bore line and directed to the left. A force applied by the shooter's shoulder (F_s) opposes that of the recoil force. Forces applied by the face and hands are indicated by F_f, F_{h1} and F_{h2}. The rifle's weight is indicated by F_w. An inertia force (F_i) opposes the movement of the rifle. D_1 indicates the distance between the point of contact of the rifle on the shoulder of the individual and an extension of the bore line, and D_2 indicates the distance between the center of gravity and the bore line. D_1 and D_2 represent moment arms which cause rotation of the rifle about the shoulder. Since D_1 and D_2 are not zero on U.S. military rifles in use at the present time and there is movement of the rifle on firing, there is a rotation of the rifle about the shoulder.

The rotation of the rifle about the shoulder is affected by the physique of the shooter, the firing position, the weight and center of gravity of the rifle, the configuration of the rifle, and the weight and velocity of projectile, and it is a major cause of dispersion. When firing conventional weapons, on which D_1, D_2 and F_r are large, a high level of skill is required to demonstrate good marksmanship. To maintain a uniform rotation of the rifle from shot to shot the rifleman must be trained to position the rifle in the same manner and to apply the same forces to the rifle.

Because of rotation of the rifle about the shoulder, a lightweight rifle is less effective when fired automatically than when fired semiautomatically (3). When several shots are fired from a single barrel with a single trigger operation there is a time interval between the exit of the individual bullets. This time permits some rotation of the rifle between the exit of individual bullets and, therefore, the hit of each following projectile is at a greater distance from the impact of the first shot until the shooter applies a sufficient force to the rifle to change its direction of movement.

A change in weight and center of gravity of the rifle results when firing a conventional, magazine-type rifle because of ammunition expenditure. This causes a variation in rotation and consequently a change in the center of projectile hits. The M14 rifle, the present standard U.S. rifle chambered for the caliber 7.62-mm NATO cartridge, has a 20-round magazine. Changes of 11 percent in the rifle's weight and 25 percent in D_2 occur when firing 20 rounds from the magazine. This causes a change in center of impact of projectiles on the target of sufficient magnitude to be observed in field firing (3).

The inertia force causes bending of the barrel during recoil. This would not be a serious consideration were the bending uniform from shot to shot. However, there is a variation in the inertia force since it is a consequence of the rotational acceleration. Because there is a variation in the bending from shot to shot, barrel rigidity is a factor of accuracy (5).

Recoil is a major factor of rifle effectiveness and it involves psychological, as well as physiological and mechanical factors. When a rifle such as our present military rifle is fired, the shooter is subjected to a loud noise and he receives a sharp blow on the face and shoulder. It is natural for an individual to react under these conditions. Also, should the rifle produce discomfort during firing, the individual is likely to react by flinching or pushing on the butt with the shoulder when he anticipates the firing of the shot. It is important that the shooter not react to firing of the shot but that he hold for some time after the trigger has been operated to permit the bullet to exit from the bore in the same manner from shot to shot. Any change in the force applied to the rifle by hands, face or shoulder or any change in the position of the rifle will affect the rotation of the rifle about the shoulder and consequently an increase in dispersion and a change in center of impact will result. Also, it is important that the shooter retain a mental picture of the sight alignment at the instant of firing. The effect of recoil is difficult to evaluate fully because, should the individual develop a practice of bucking the rifle or closing his eyes when the rifle is fired, he may continue to do so even when firing a rifle having a light recoil. Small changes in recoil cannot be readily observed in firing and for this reason muzzle brakes, which may reduce recoil as much as 40 percent, show no improvement in effectiveness in field firing (1,6). Muzzle attachments such as muzzle brakes have the disadvantages of increasing the noise level at the shooter's position, of increasing the weight and overall length of the rifle, and they may affect the accuracy adversely (5).

The effectiveness of the rifle depends greatly on its configuration. For maximum effectiveness the rifle should provide small moment arms, D_1 and D_2, it should permit the shooter to assume normal firing positions, and it should fit the physique of the individual shooter. The stock provides a handle for the rifle. It is advantageous that the grip provide a support to the hand and permit effective trigger operation. The forward section of the stock should provide a grip for the other hand and the comb should have the correct height with respect to the line of sight to provide a support for the face. The shape of the stock should be such that it does not strike the face during recoil. The butt should be equipped with a material which will fit the contour of the shoulder and which will not slip on the clothing during firing. The configuration of the stock was formerly restricted because of the materials available. Wood is not a completely satisfactory material for military rifle stocks. Because it has limited strength it is necessary to orient the grain of the wood and to use a large cross-sectional area where considerable strength is required. When exposed to the atmosphere, the shape, dimensions and weight of the wood stock change with the weather when the grain is not sealed with a finish because of variations in moisture content. This affects the forces against various metal parts which are in contact with the stock. The barrels on U.S. military rifles are connected to the stocks so that variations in the stock will affect the bending of the barrel. Also, it is customary to dip the wood stock in oil after it is finished. This stains the wood but it does not seal the grain. Stocks made of wood are costly to manufacture because they must be machined from a single plank.

The use of wood as a stock material has imposed some restrictions on configuration but there has been no attempt to fit the stock to the individual shooter. While a large number of clothing sizes are provided for our soldiers, a single rifle stock is provided. It is possible however that a rifleman's effectiveness depends more on the fit of his rifle than on that of his clothes. About 15 percent of the soldiers are left handed or they shoot from the left shoulder because of a left master eye. Nevertheless, they are required to use a rifle designed for a right-handed shooter.

The M14 does not permit all individuals to assume normal firing positions because of interference with a protruding magazine and an exposed operating rod. The butt is equipped with a steel butt plate which does not fit the contour of the shoulder and which has a tendency to slip on the clothing. While the stock is convenient to manufacture and it fits the shooter of average physique to a fair degree, a large moment arm causes sufficient rotation of the rifle for the stock to deliver a blow to the face.

The time required for the firing mechanism to function and for the bullet to pass through the bore is of considerable importance to the rifleman. The rifleman generally has a holding error which requires a high degree of coordination between trigger operation and sight alignment with the target to make a hit. When the time between operation of the trigger and exit of the bullet from the bore is appreciable, the bullet will not hit at the point of aim when the trigger was operated but will hit at some point along the path described by the sight alignment, assuming that the shot is fired in a normal manner. This requires that in order to make a hit on a small target, the shooter must have a small holding error or he must operate the trigger before the sights become aligned with the target. The time required for the firing mechanism to function and for the bullet to pass through the bore becomes increasingly important as the velocity of the rifle or target is increased. The design of the firing mechanism on the M1 and M14 rifles permits convenient disassembly but the time required for functioning is comparatively large. Because a high degree of coordination is required to operate the trigger with respect to sight alignment, it is advantageous to have a trigger mechanism which can be operated quickly and positively. It is customary on U.S. military rifles to use a trigger mechanism which requires a heavy force and a long movement for operation. The average force required to operate the trigger on 21 M14 rifles was found to be 6.2 pounds (5).

The accuracy capability of the rifle-ammunition combination is a major factor in rifle effectiveness. It is important that the rifle be capable of producing a small dispersion with a constant center of impact. The limitation of accuracy of the present standard U.S. military rifles was most readily observed when firing deliberately at a moderate range but it was also observed when firing at a short range on short-exposure time targets where the sighting error was large (1).

It has been possible to obtain comparatively good military rifle accuracy when using a special match cartridge with particular rifles of previous U.S. military models which were selected from lots especially assembled with selected and hand-fitted components. While it is customary to equip the rifleman who shoots for sport and training in military competitions with such a rifle-ammunition combination, the combat rifleman whose life may depend on his accuracy of fire may be required to use a rifle-ammunition combination which has a dispersion ten times as great as that of the combination used by the competitive rifleman (5,8,9). The average accuracy of the rifle-ammunition combination issued to the combat rifleman is poorer than that of sporting rifles and ammunition, and that of the most recent model is somewhat poorer than that of the previous model (1,3,7).

Barrel mass is a factor of effectiveness not only because it affects the weight and center of gravity of the weapon but because the barrel acts as a heat reservoir. When the barrel mass is small and the heat generated by the propellant and friction of the bullet in the bore is great, heat is dissipated to the atmosphere at such a high rate after firing a few shots as to cause an increase in sighting error.

It is cusomary to use the military rifle as a handle for a bayonet or grenade launcher. In addition, the rifle may be equipped with stacking swivel, flash suppressor, muzzle brake, cleaning kit and tools. The addition of each of these items increases the weight of the rifle and it may affect the rifle's configuration and accuracy adversely.

Optical sights permit a smaller sighting error under all levels of illumination than metallic sights but this gain in performance is obtained with an increase in weight, a less desirable configuration, a reduction in field of view , and a more critical eye position (2). The aperture is the most effective type of metallic sight. It is advantageous to have the rear aperture sight between two and four inches from the eye, and the front sight should be positioned as far forward as the configuration of the rifle will permit. The most advantageous size or magnification of rifle sight is dependent upon the target, level of illumination, weather and training of the individual.

In a test of 20 weapon-sight combinations representing current military and sporting rifles on short-exposure-time targets the M14 and M1 rifles ranked fourteenth and fifteenth in effectiveness and they were superior only to rifles equipped with inferior sights (1).

The greatest variable, other than weather, in rifle effectiveness when using conventional weapons is the individual shooter. In the initial phase of the 1960 APG test the average figure of merit for the least skilled shooter was 3.2 times that of the most skilled. Assuming normal participants, training is the most important single factor in rifle marksmanship. While there are other factors of physique, physical condition, eyesight, reaction time, coordination and self discipline, there is good correlation between the performance of the shooter and his training. It is expected that some individuals have more native ability than others, but the characteristics of reaction time, coordination and self discipline are developed largely through training. The average f.m. for three Army shooters, whose marksmanship training was limited to that obtained in the service except for a small amount of hunting experience by one individual was 2.2 times that for seven shooters who had training other than or in addition to military marksmanship training. No correlation between the marksmanship rating indicated on the soldier's personnel record and his ability on short-exposure-time targets was observed. An improvement in effectiveness of from 8 to 52 percent was observed for the ten shooters in firing this test phase in a period of two months, the greatest improvement being demonstrated by the less skilled shooters. When the sighting error only was recorded the least experienced of five participants had an average dispersion 2.6 times that of the most experienced (4). The least experienced individual reduced his dispersion by 33 percent in three days and the most experienced by 8 percent. Three experienced individuals reduced their dispersion by one half in conducting four phases of the 1961 APG sighting error test (2).

Greater rifle effectiveness is possible through rifle and ammunition design, and marksmanship training.

A reduction in recoil (and consequently a reduction in rotation of the rifle about the shoulder), weight of both rifle and ammunition, bore time, and height of trajectory can be accomplished by using a small-caliber high-velocity round. An improvement in configuration, durability and accuracy performance can be obtained by use of a better stock material. The configuration can be improved by selecting a mechanism which permits the shooter to assume normal firing positions, by minimizing the moment arms which cause rotation, by fitting the stock to the individual shooter, and by eliminating those parts which have no function in projecting the bullet to the target. The time between trigger operation and bullet exit can be further reduced by improving the firing mechanism. Greater rigidity of barrel and stock can be obtained by improved design. The sighting error can be reduced with an optical sight. Improved trigger control can be accomplished with a trigger mechanism which operates with a light force and a short movement.

REFERENCES

1. Report No. DPS-87 by L.F. Moore and titled "A Comparison of Rifle Effectiveness When Firing at Short-Exposure-Time Targets".

2. Report No. DPS-394 by L.F. Moore and titled "A Test to Investigate Various Factors of Sighting Error".

3. Twenty-Second Report on Project No. TS2-2015 by L.F. Moore and titled "A Test of Rifle, Lightweight, Caliber .30, T44 and Rifle, Lightweight, Caliber .30, T47".

4. Forty-Fourth Report on Project No. TS2-2015 by L.F. Moore and titled "A Test of a Sighting-Error Recorder".

5. Report No. DPS-471 by L.F. Moore and titled "Tests for Ad Hoc Committee on Accuracy and Targeting of 7.62-mm Ammunition and M14 Rifles".

6. Report No. DPS-439 by D.R. Davis and titled "Test of Muzzle Attachment Designed by Gun Products, Inc. for the M14 Rifle".

7. Report No. DPS-384 by L.F. Moore and titled "A Test of Twenty-One Rifles, 7.62-mm, M14 Received from the U.S. Marine Corps".

8. Thirty-Ninth Report on Ordnance Corps Project No. TS1-2 by L.F. Moore and titled "A Test of Cartridge, Caliber .30, Match, T291 (M72)".

9. Firing Record No. S-46276 by L.F. Moore "To Provide Accuracy, Pressure, Time-of-Flight, Velocity and Wind-Deflection Data on Several Caliber .30 (7.62-mm NATO) Rounds.

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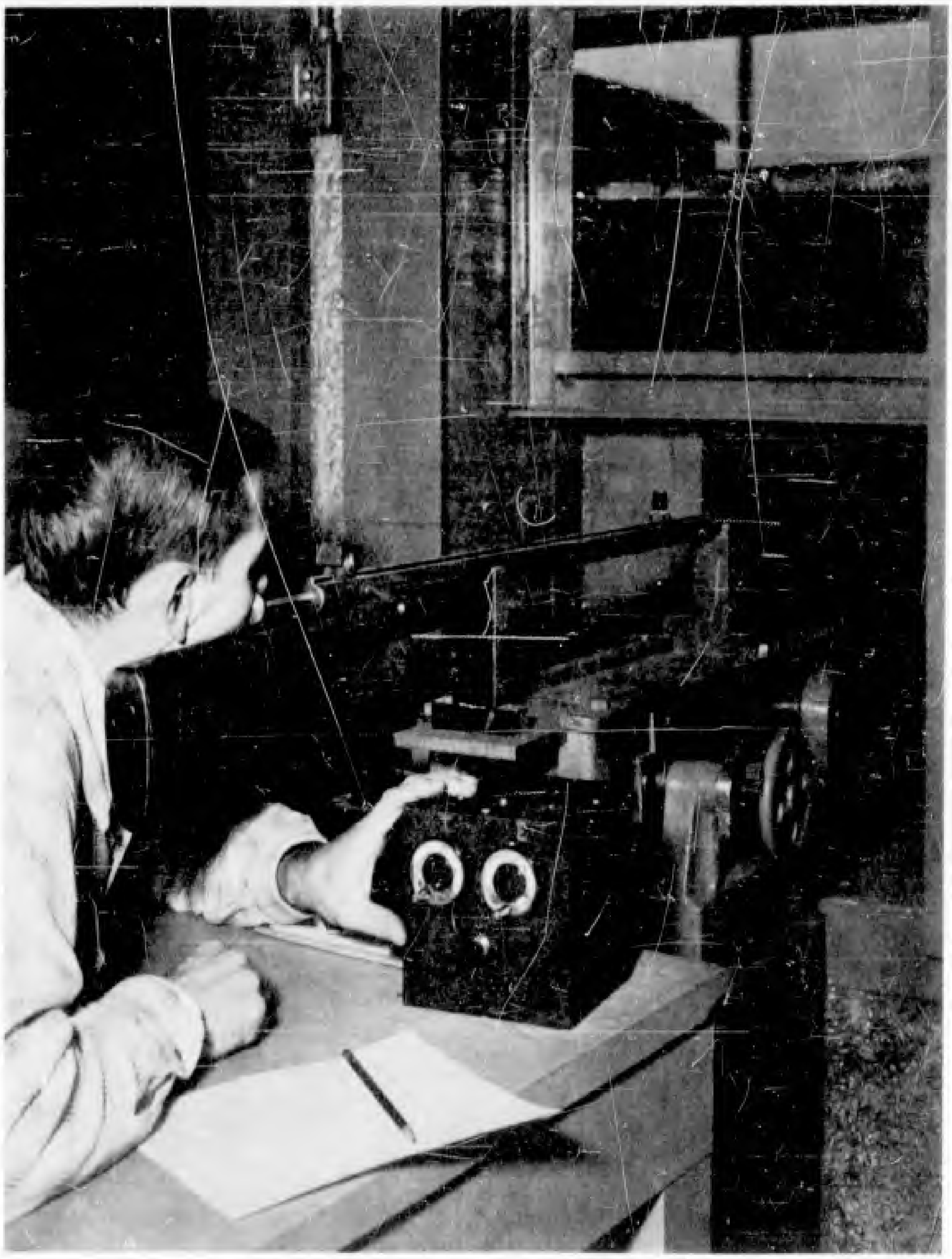
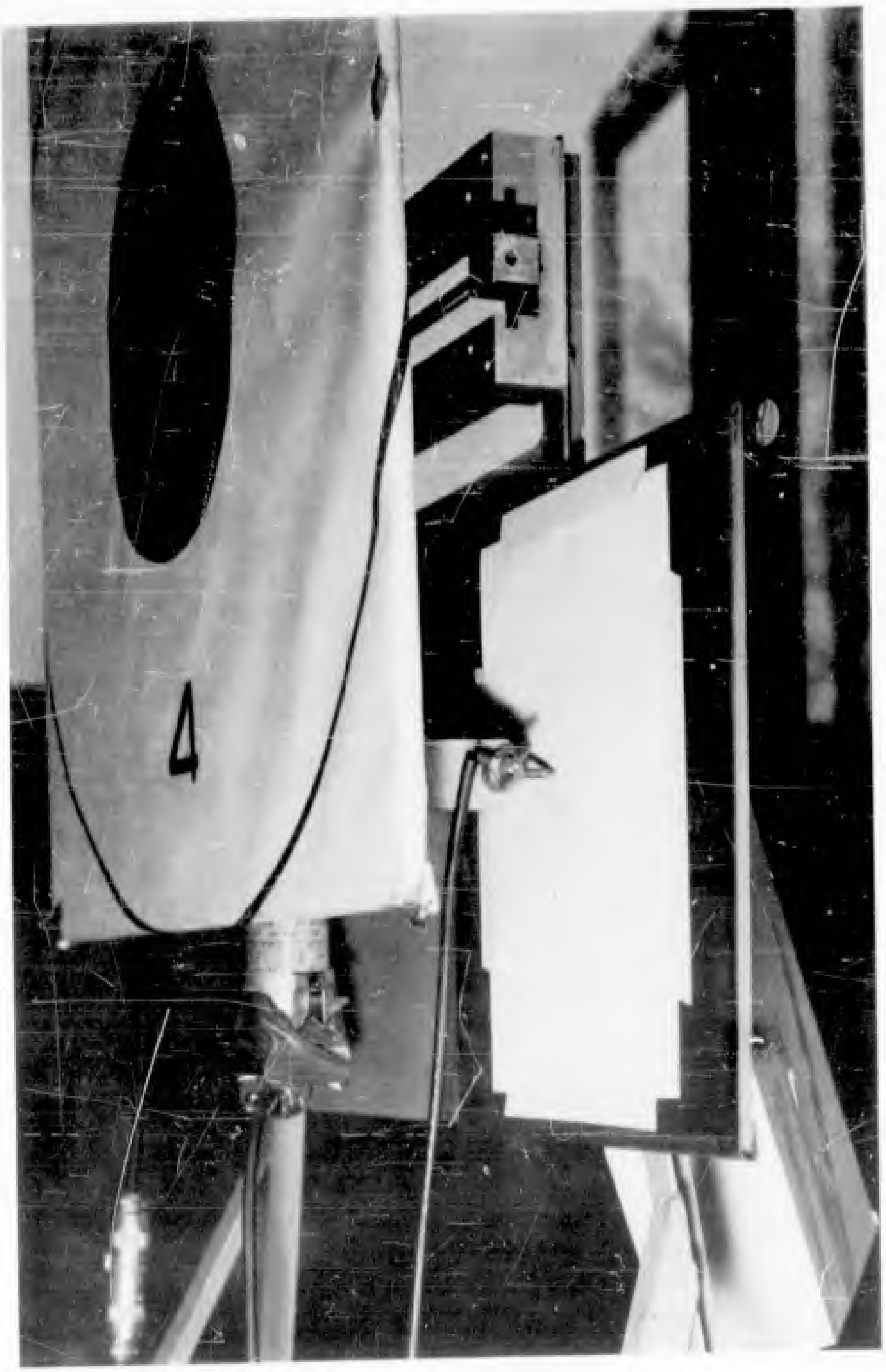


ABERDEEN PROVING GROUND

B12955 7 December 1955
An individual conducting an exercise with the sighting error recorder using M1 rifle sights.



ABERDEEN PROVING GROUND

B12958 19 October 1959
A spark passes through a sheet of paper indexed on the record plate to show sight alignment.

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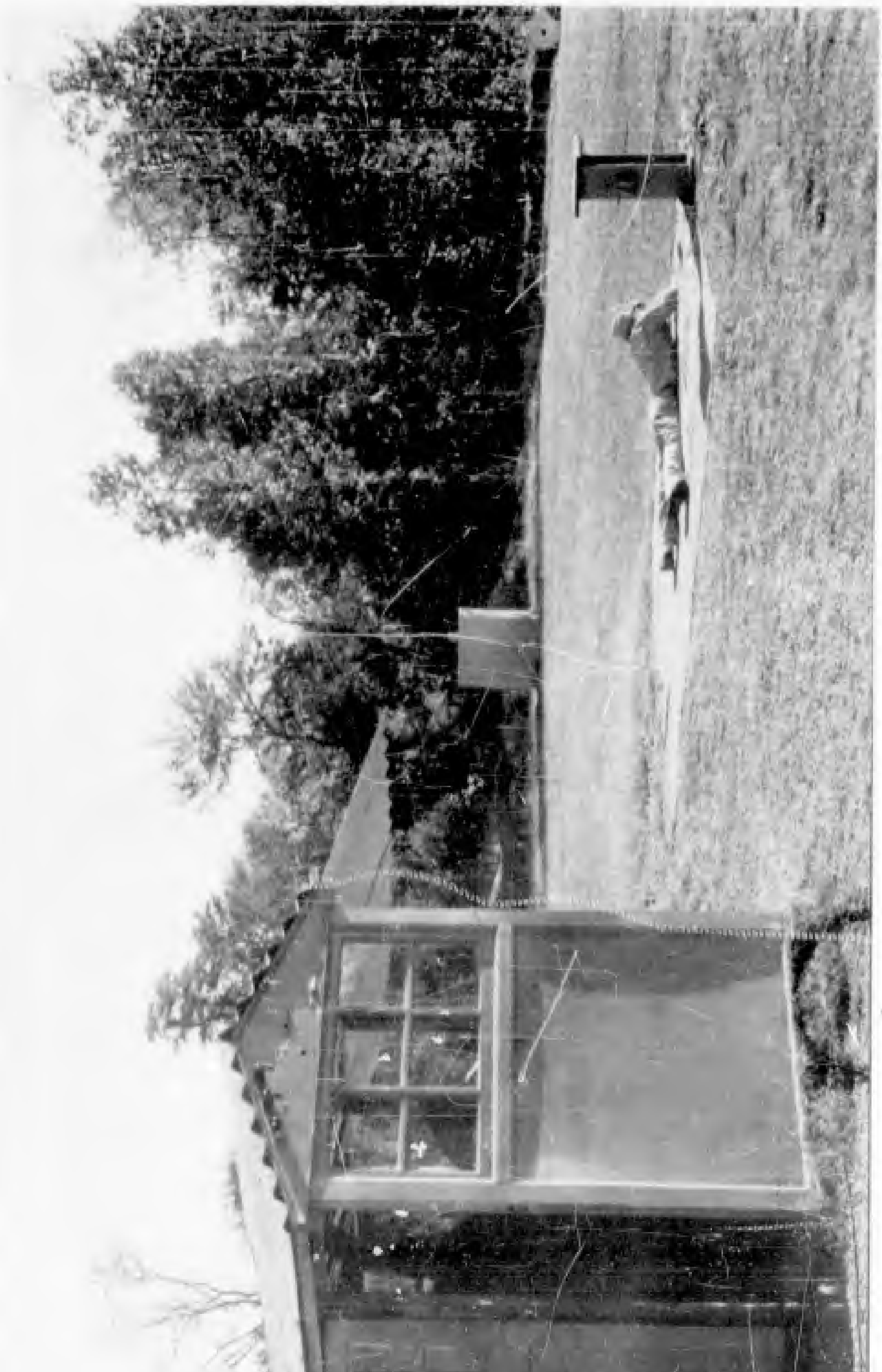

ABERDEEN PROVING GROUND

59P705 19 October 1959
Range facility used in rifle effectiveness test. Target number 2 is exposed to the shooter firing from the prone position.

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Free body diagram

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